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DELIVERING "DESIGNED" CFM OF OUTSIDE AIR TO THE OCCUPANTS, PROBLEMS AND SOLUTIONS

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ABSTRACT

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recently proposed an increase in the minimum amount of outside air that should be designed for and delivered to occupants in indoor office-type environments. This paper will present the assessments of several buildings in which ventilation was "designed" to be adequate but, when field tested years later in response to complaints of indoor air quality problems, was found to be incapable of delivering the design quantities of ventilation air. These situations were often caused by measured short circuiting in the heating, ventilating and air conditioning system, improper installation of HVAC equipment, or poor preventive maintenance. The results of corrective measures are detailed.

INTRODUCTION

In the process of conducting indoor air quality investigations in office-type buildings, the authors have identified several important areas that need to be evaluated. These include, but are not limited to, the history of the occupant complaints, the distribution of outside air to the occupants, and the sources of potential irritants located both inside and outside the building. The overall techniques utilized in conducting these investigations are described elsewhere (Bearg and Turner 1985, 1987). This paper focuses on the evaluation of the amount of outside air being distributed to the occupants.

In determining the amount of outside air made available to the occupants, we have identified three important questions:

1. What was the space originally designed to be? (What was the original intent of the design, based on drawings, specifications, and design quantities or does anybody know?)

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2. What is it currently being used for?
(Based on inspection and defensible measurements, what is really happening there?)

3. What do we want to be happening?
(Based on current and planned space usage and the current and evolving guidelines concerning the quantitites of outside air that are considered desirable to deliver to occupants, what should be happening?)

ASSESSMENT METHODOLOGIES

Original Design

The determination of the original intent of a design (i.e., what was supposed to be happening in this space) may be as simple as finding the original design drawings and specifications and extracting information. For older buildings, this can be a tedious chore and success may be determined by luck, not by skill. The task is often easiest when the building is owner-occupied, and the original owner has been there since the building was constructed.

Historic and Current Situation

The determination of what is currently happening in this space, and possibly in the recent past, is a matter of meticulous inspection, testing, and measurement. By inspection and communication with the owner, one can often determine the building's actual occupancy, space utilization, and evidence of HVAC preventive maintenance. Historical conditions can be inferred from the situation as found. The actual amounts of outside air being delivered to a space, however, can be evaluated only by testing and measurement. This testing must, at a minimum, include the inspection and testing of all controls that affect the delivery of ventilation and outside air to the occupants and the actual measurement of the quantities of outside air and/or total air in question. Equipment and techniques that the authors have found useful in producing defensible results include the use of velocity-measuring devices such as pitot tubes and airflow hoods and anemometers, temperature and humidity probes for determining enthalpy balances at HVAC air-handling units that supply outside air, and static pressure sensors for determining pressure relationships within air handling units and building envelopes. All equipment utilized must be calibrated in order to develop accurate, defensible results. The approach that the authors have found indispensible in assessing the amount of outside air actually delivered to occupants is the combined use of tracer gas measurements, enthalpy balance testing, and velocity measurements. The combination of these techniques will allow both measurement of designed outside air flows and supplemental infiltration/exfiltration to be addressed if conducted under appropriate weather conditions.

The tracer techniques utilized have included a modified version of the ASTM methodologies and methodologies currently being developed by National Bureau of Science (NBS) researchers (ASTM 1980; Persily and Grot 1985). Sulfur hexafluoride (SF6) is the tracer most often utlized by the authors. It has been chosen because of its detectability at very low levels with portable gas chromatographic equipment, its inert nature, and its limited normal usage in occupied buildings. Another technique that has been useful as a survey tool in assessing areas of potentially low outside air supply is the utilization of carbon dioxide (CO2) measurements, using a real-time calibrated CO2 infrared detector and ASHRAE calculation methodologies (Persily and Grot 1985; ASHRAE 1981).

The authors have found that the achievement of design values of outside air can never be assumed without at least validating the most recent air balancing data and the current correct operation of the ventilating equipment.

Recommendations for Solutions

Once a good understanding of the current situation has been developed, recommendations can be made concerning the supply of adequate outsie air to the occupants. It is the opinion of the authors and several other researchers that many current building codes do not adequately specify the quantities of outside air that are necessary to provide conditions that will be considered acceptable in many of today's office environments.

Based on the current state of knowledge about this matter, the authors recommend the proposed ASHRAE 62-1981R minimum ventilation guidelines (ASHRAE 1986), which can be expected to be adequate for situations for which there are no known sources of contaminants in a space or building. Whenever the potential irritation of occupants in a confined space by identifiable sources, such as emissions from tobacco smoking, wet process photocopiers and large dry process copiers, or other potential point sources is suspected, special ventilation provisions are suggested. Typically, we recommend isolation of the source from the return air system and the use of a localized exhaust ventilation system as the most effective strategy.

PROBLEMS IDENTIFIED TO DATE

Based on indoor air quality evaluations that have been conducted by the authors since 1984 in office environments, the following are examples of problems concerning the delivery of outside air to the occupants of a building.

These situations relate to insufficient amounts of outside air being drawn past the dampers.

Situation A, Building Overpressured

In this example, the installed HVAC system in an office building was unable to deliver designed outside air and total air to the building due to installation errors. The HVAC system consisted of a pre-packaged rooftop-mounted heat pump (with a field-installed economizer cycle), ducted supply, zone, and returns. Investigation of the control circuitry revealed that the building exhaust fans never operated due to improperly wired circuitry. This caused excessive positive pressure in the building (approximately .05" water, static pressure), which reduced airflows and resulted in difficulties in providing adequate free cooling air. In addition, a defective outside air damper control and the invalid assumption in the balancing report of a 10% outside air leakage rate lead to the outside air being "off" for at least a year.

Additional deficiencies of the system included an improperly adjusted warm-up cycle control, which may have also contributed to low outside air quantities by keeping the dampers closed after building occupancy. Poor zoning also led to local overheating due to the inability of the cooling equipment to respond to solar gains at the building's perimeter. The renovation of this building, prior to this occupancy, included the installation of unopenable windows that reduced infiltration, but did not include the installation of a continuous vapor barrier.

Further tracer gas testing has revealed that, in fact, even with the outside air dampers closed, approximately 1.25 air changes per hour of air was being moved through the building during relatively mild conditions. Thus, uncontrolled leakage due to a permeable shell is suspected of causing too much outside air to be supplied during severe winter weather, leading to extreme dryness and occupant discomfort.

The recommended solution includes the re-design of the system with adequate zoning to allow a response to solar gains and a complete checkout of the control logic for the HVAC economizer operation.

In addition, further investigation of the building's shell leakage through the use of infrared thermography and subsequent caulking is being investigated.

As this building has a high occupant density and was designed to recent energy codes, it is expected that the minimum position location of the outside air damper will need to be at approximately 30%, after the uncontrolled leakage is reduced.

Situation B, Lack of Minimum Open Position for OA Dampers

This situation has been observed for a number of reasons:

(1) There is the unsubstantiated belief that outside air dampers in the closed position still permit 10% to 15% leakage,

which may have been true at one time but is definitely not true now. Also, the control for a warm-up cycle was set at too high a temperature and so kept the outside air dampers closed for a longer interval in the morning than was intended, despite the fact that the building was occupied.

Situation C, Damper Control Out of Calibration

Another control-related problem occurred in a building where the mixed air sensor controller was out of calibration. Instead of seeking to cool the return air from 70F to 60F with the introduction of outside air, the sensor controller was seeking 70F and so kept the outside air dampers closed.

These following situations had sufficient quantities of outside air being drawn past the dampers, but there were problems with the delivery systems.

Situation D, Ducts Were Sized to be Too Small

This situation involved a building in which the installed HVAC equipment was unable to deliver design quantities due to flaws in the design. This constant volume HVAC system consisted of both ducted supply and ducted return, with no economizer mode. An original 20-year-old balancing report documented the HVAC system's inability to deliver specified outside air and total air quantities due to inadequate duct sizing. These deficiencies resulted in air quantities that were approximately 40% of design on the average with a range of 25% to 60%. Since this building was designed to standards developed before the energy crunch of 1974, the delivered quantities may be tolerable in this low-occupant density building. This situation has yet to be resolved, the project is ongoing.

Situation E, Leakage from Outside Air Supply Directly to Building Exhaust

In this office building example, the installed HVAC system was unable to deliver the designed quantities of outside air to the occupants. This was due to a number of factors including the fact that the use of the space was radically different from the original design for the building. The HVAC system was a constant volume, nonrecirculating type with a pressurized ceiling plenum supply, area exhausts, and no economizer mode. The original HVAC design was for residential apartment/condominium occupancy and was not sufficient for the ultimate office use. Aside from this change in space usage, tracer gas measurements revealed a complete inability of the pressurized ceiling plenum design with limited zoned exhaust ducting to distribute the outside air to the occupants. There was gross short-circuiting through duct leakage, which prevented the outside air that was being delivered to the ceiling plenum from ever reaching the occupants within the space, and the limited height of the ceiling supply plenum contributed to the distribution problem. All of these IAQ problems were aggravated by inadequate HVAC system maintenance and a lack of understanding by the maintenance staff of the system.

The recommended solution was to completely re-design the HVAC system for adequate supply and distribution or to dramatically alter the use of the building to very low occupancy or to the original residential purpose.

Situation F, Short-Circuiting of Supply Air to Return Air

In this school building, the installed HVAC system was unable to deliver designed outside air quantities to the occupants due to inadequacies in the installation details and design specifications. In this case, the HVAC system was of the constant volume type with an economizer mode. The distribution system consisted of a light troffer diffuser supply system with ceiling plenum return. Flow measurements revealed that short-circuiting was occurring at the site of the light fixture-diffuser outlet interface, allowing 30% to 50% of the supply air to short-circuit directly from the diffuser outlet to the return air plenum, without ever entering the occupied space. This problem occurred in a building of modern vintage (with high occupant density) such that this 30% - 50% reduction in delivered air quantities resulted in the delivery of approximately 5 cfm outside air per person or less; it is now widely accepted that 5 cfm outside air or less is inadequate to maintain acceptable IAQ unless special air cleaning is utilized. This problem was corrected by sealing the troffer diffuser to the light fixture through the use of a gasketing material and increasing outside air minimum set points.

CONCLUSIONS:

Through detailed investigation of actual airflows and operational parameters of the HVAC systems of numerous buildings, it has been shown by many researchers (including the authors) that an inadequate supply of "fresh" outside air has contributed to occupant discomfort and complaints of poor indoor air quality.

The inadequate supply of outside air may be caused by several factors, including outdated design standards (or building codes), the defective installation of the HVAC equipment, overloading by human occupancy densities much greater than the original design, or inappropriate operations and maintenance practices.

If ventilation inadequacies are expected to be identified and resolved, the assessments of outside air supply can only be accurately determined with defensible on site ventilation measurements, which must include an assessment of the actual outside air delivered to the occupants.

It is a challenge for today's HVAC and building designers to design systems that will not only minimize energy consumption but also provide occupant comfort. These systems must be installed correctly and maintained to operate as designed.

Building owners and occupants must be made aware of the limitations of the design, so that systems do not become overloaded, or inappropriate air contaminants added.

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